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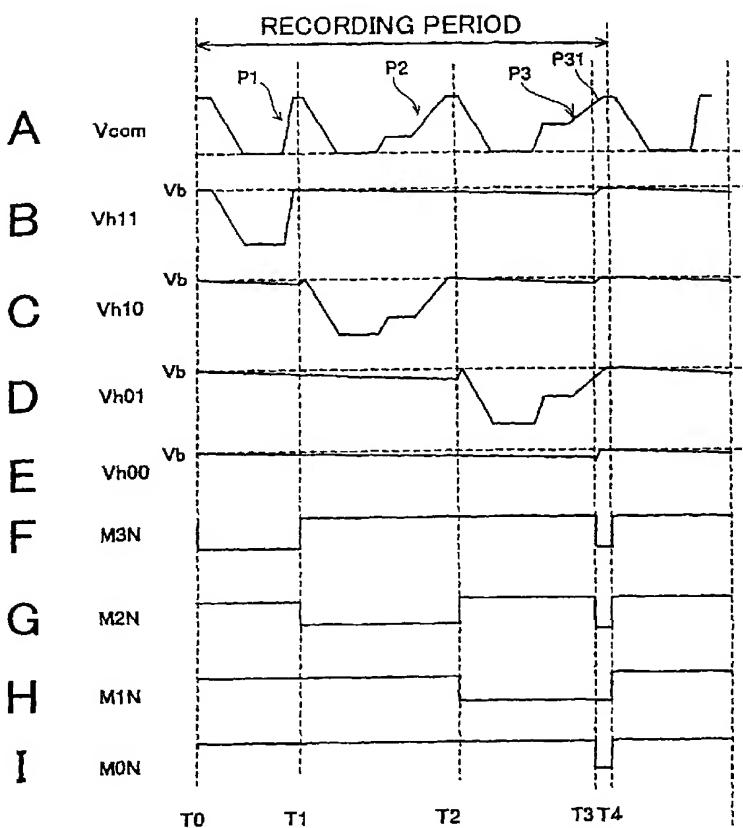
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(57) **Abstract:** There is provided a head control device able to re-charge an electromechanical transducing element with a driving pulse without requiring an additional re-charging time period in a recording period. The driving signal includes a plurality of driving pulses, and in each recording period, at least one driving pulse includes a portion varying from a discharging level to a medium level to charge the piezoelectric element to eject a liquid droplet, and a subsequent portion varying from the medium level to a target level to re-charge the piezoelectric element to the target level.



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DESCRIPTION

HEAD CONTROL DEVICE AND IMAGE RECORDING APPARATUS

5 TECHNICAL FIELD

The present invention relates to a head control device and an image recording apparatus, more particularly, to a head control device that controls a liquid droplet ejection head including an 10 electromechanical transducing element, and an image recording apparatus having the head control device.

BACKGROUND ART

An inkjet image forming apparatus, such as a 15 printer, a facsimile machine, a copier machine, or a plotter, comprises an inkjet head to eject ink droplets to record images. The inkjet head has nozzles through which ink droplets are ejected, ink flowing paths usually including chambers for applying pressure to the ink 20 therein and in communication with the corresponding nozzles, an ink feeding path, and so on, and portions for creating and applying pressure to the ink in the flowing paths to eject ink droplets. There are also devices for ejecting other kinds of liquid droplets, for example, 25 those ejecting droplets of liquid resists, and those

ejecting droplets of DNA samples.

In an inkjet head, various methods are employed to apply pressure to the ink in an ink flowing path so as to form droplets of ink and eject them. The 5 following methods are well known in the related art.

Japanese Unexamined Patent Publication No. 2-51734 discloses an inkjet head in which an 10 electromechanical transducer, for example, a piezoelectric element (a piezoelectric crystal), is used as a vibrating plate to form a vibrating wall of a chamber to apply pressure to the ink (the pressure application chamber). When the crystal receives a charge, the vibrating wall deforms and vibrates, therefore changing the volume of the ink chamber and forcing some 15 of the ink in the chamber out through the nozzle. This is the so-called "piezoelectric inkjet head".

In addition, Japanese Unexamined Patent Publication No. 61-59911 discloses another inkjet head in which a resistor is used in each pressure application 20 chamber to create heat; this heat vaporizes the ink in the chamber and creates a bubble. As the bubble expands, some of the ink in the chamber is pushed out by the pressure. This is the so-called "thermal inkjet head".

Further, Japan Unexamined Patent Publication 25 No. 6-71882 discloses still another inkjet head in which

an electrode is placed facing a vibrating plate that forms a wall of each pressure application chamber. Because of the electrostatic force created between the electrode and the vibrating plate, the vibrating plate 5 deforms and vibrates, therefore changing the volume of the chamber and forcing some of the ink in the chamber out through the nozzle. This is the so-called "electrostatic inkjet head".

The inkjet heads mentioned above exhibit two 10 kinds of methods of forming ink droplets. In one of them, a vibrating plate is pushed inward relative to the pressure application chamber, decreasing the volume of the chamber, and forcing some of the ink out. In the other method, a vibrating plate is pulled outward 15 relative to the chamber and thus expanding the volume thereof; then the vibrating plate deforms so as to recover from the expanded shape to its original shape, and therefore, forces some of the ink out.

In an inkjet head using the second method 20 (pulling the vibrating plate), as an initial state, a bias voltage is applied to the piezoelectric element to charge the element. Then the piezoelectric element discharges (releases the stored charge), leading to contraction of the piezoelectric element. Accordingly, 25 the volume of the chamber increases, and this pulls more

ink into the chamber from outside, for example, the ink feeding channel. Then, a driving signal is applied to the piezoelectric element to charge the element rapidly, causing rapid expansion of the element, and this rapidly 5 decreases the volume of the chamber and forces some ink droplets out through the nozzle.

Next, with reference to FIG. 12 and FIGs. 13A through 13H, explanations are made of the operations of a head control device for controlling an inkjet head that 10 employs the second method to form three kinds of ink droplets (referred to as "dots" below) by using the d33 mode of a piezoelectric crystal.

FIG. 12 shows a head control device of the related art.

15 In the head control device shown in FIG. 12, a driving signal V_{COM} including a number of driving pulses (shown in FIG. 13) is output from a driving signal generator 101, and is input to a piezoelectric element 103 through a switch 102. The switch 102 is switched ON 20 or switched OFF depending on the output signals of a decoder 104 through a level shifter 105.

The decoder 104 includes gate circuits 110 through 112, which receive recording data signals L_0 , L_1 , L_2 stored in a not-shown memory and gate signals M_0 , M_1 , 25 M_2 , respectively, whose levels are controlled within a

recording period so as to select the desired recording data, and an OR circuit 113 that sends the signals from the gate circuits 110 through 112 to the level shifter 105.

5 Here, it is assumed that a small dot is to be formed when $L_0 = 1$, a medium dot is to be formed when $L_1 = 1$, and a large dot is to be formed when $L_2 = 1$; further, when $L_0 = L_1 = L_2 = 0$, the piezoelectric element will not operate and no dots are formed.

10 FIGs. 13A through 13H show timing charts of signals in the head control device in FIG. 12 when operated to form the above dots. Specifically, FIGs. 13A through 13H show waveforms of the driving signal V_{com} , signals selected from the driving signal V_{com} and applied 15 to the piezoelectric element, and the gate signals M_0 , M_1 , M_2 .

When a large dot is to be formed, that is, when $L_2 = 1$, by setting $M_2 = 1$ in the period from the time T_{10} to the time T_{11} as shown in FIG. 13F, a driving 20 pulse for forming a large dot as shown in FIG. 13B is extracted from the driving signal V_{com} and applied to the piezoelectric element 103.

In addition, when a medium dot is to be formed, that is, when $L_1 = 1$, by setting $M_1 = 1$ in the period 25 from the time T_{11} to the time T_{12} as shown in FIG. 13G, a

driving pulse for forming a medium dot as shown in FIG. 13C is extracted from the pulses in the driving signal Vcom and applied to the piezoelectric element 103.

When a small dot is to be formed, that is,
5 when $L_0 = 1$, by setting $M_0 = 1$ in the period from the time T_{12} to the time T_{13} as shown in FIG. 13H, a driving pulse for forming a small dot as shown in FIG. 13D is extracted from the pulses in the driving signal Vcom and applied to the piezoelectric element 103.

10 In this way, by generating a common driving signal Vcom including driving pulses for forming various kinds of dots, selecting appropriate driving pulses from the driving signal Vcom according to the predetermined gate signals and recording data signals to switch ON or
15 switch OFF the appropriate channel, and applying the selected driving pulses (waveform) to the piezoelectric element, ink droplets of different sizes, in other words, dots of different grade levels, can be formed with a single driving signal Vcom.

20 In the above process, before a piezoelectric element is operated, it is preferable to apply a bias voltage to the piezoelectric element in advance to keep the piezoelectric element in a charged state (expanded condition). As described above, this charged state is the
25 initial condition of the piezoelectric element when it is

operated to form ink droplets. For example, this treatment is necessary for a piezoelectric element not required to form a dot in the present recording period. Additionally, even for a piezoelectric element that has 5 been operated to form a dot in the present recording period, it is still preferable to keep the piezoelectric element in a charged state before the next driving pulse is applied.

However, in a head control device having the 10 above configuration, for example, considering a piezoelectric element not forming a dot in the present recording period, even then a bias voltage is applied in the preceding recording period and the piezoelectric element is kept in a charged state by that bias voltage. 15 Because of natural discharge of the piezoelectric element, the potential of the element decreases in the present recording period.

Due to this, when a driving pulse for ejecting an ink droplet is applied in a following recording period, 20 because the potential right before ejecting is too low, it is difficult to form an ink droplet containing a desired amount of ink.

In the same way, for a piezoelectric element that has been operated to form a dot in the preceding 25 recording period, in the duration in which a driving

voltage is not applied to the piezoelectric element, the natural discharge occurs. If this duration before a driving voltage is applied is long, the potential of the piezoelectric element decreases noticeably because of the 5 natural discharge; consequently, even if a desired driving pulse for ejecting a desired ink droplet is selected and applied in the present recording period, since the potential right before ejecting is too low, it is difficult to form an ink droplet containing a desired 10 amount of ink.

As a solution to this problem, Japanese Unexamined Patent Publication No. 2001-10035 discloses an inkjet recording apparatus in which, at a specified timing in each recording period, a bias level is selected 15 from the driving signal to re-charge the piezoelectric element to the bias level.

However, in the above inkjet recording apparatus, a time interval related to the re-charging level has to be allocated in the driving signal. The 20 length of the time interval is determined taking the reaction time of a switch into consideration, that is, the duration from the time when a switching command is issued to the time when the switch is actually switched ON or switched OFF. Usually, the time interval should be 25 set relatively long.

However, in order to increase image formation speed, it is desirable to make the ink droplet ejection period short, so it is difficult to secure an additional re-charging time period that is irrelevant to ink droplet 5 ejection operation. Further, in order to increase the number of the grade levels to improve image quality, it is required to allocate more pulses in the driving signal, and this also makes it difficult to secure the additional re-charging time period in the driving signal.

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DISCLOSURE OF THE INVENTION

Accordingly, it is a general object of the present invention to solve the above problem of the related art.

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A specific object of the present invention is to provide a head control device able to re-charge an electromechanical transducing element with a driving pulse without providing an additional re-charging time period in a recording period, and an image recording 20 apparatus having the head control device.

To attain the above objects, according to a first aspect of the present invention, there is provided a head control device that applies a driving signal to an electromechanical transducing element to change a shape 25 of the electromechanical transducing element to change a

volume of a liquid droplet ejection chamber filled with a liquid to eject a liquid droplet through a nozzle in communication with the liquid droplet ejection chamber, comprising a head driving unit that generates the driving 5 signal including a plurality of cycles of a plurality of driving pulses, selects and applies one of the driving pulses to the electromechanical transducing element to change the shape of the electromechanical transducing element for ejecting the liquid droplet, each driving 10 pulse having a first portion varying from a first level to a second level for changing the electromechanical transducing element from a first shape to a second shape, and a second portion varying from the second level to the first level for changing the electromechanical 15 transducing element from the second shape back to the first shape to eject the liquid droplet, wherein in at least one driving pulse in each cycle, the second portion includes a third portion varying from the second level to a third level for changing the shape of the 20 electromechanical transducing element to eject the liquid droplet, and a fourth portion subsequent to the second portion varying from the third level to the first level for changing the shape of the electromechanical transducing element back to the first shape.

25 Preferably, the first portion discharges the

electromechanical transducing element from a first potential equivalent to the first level to a second potential equivalent to the second level, the second portion charges the electromechanical transducing element to the first potential to eject the liquid droplet, the third portion charges the electromechanical transducing element to a third potential equivalent to the third level to eject the liquid droplet, and the fourth portion re-charges the electromechanical transducing element to 10 the first potential.

According to the above aspect of the present invention, the electromechanical transducing element is re-charged by a portion (the fourth portion) of the driving pulse varying from a medium value (the third level) to the first level, but not by a signal at the first level, thus re-charging of the electromechanical transducing element can be started earlier, and consequently, the duration of re-charging becomes short.

Further, since the fourth portion is applied 20 to the electromechanical transducing element after the third portion induces liquid droplet ejection, the re-charging operation does not influence liquid droplet ejection, and this reduces the possibility of mistaken ink ejection due to re-charging.

25 Furthermore, since the fourth portion is

included in one cycle of the driving signal, it is not necessary to provide an additional time interval to allocate the signal for re-charging, so it is possible to increase the speed of image formation and improve image 5 quality.

To attain the above object, according to a second aspect of the present invention, there is provided an image recording apparatus comprising a liquid droplet ejection head including a plurality of liquid droplet 10 ejection chambers each filled with a liquid and communicating with a nozzle, and a plurality of electromechanical transducing elements in correspondence with the liquid droplet ejection chambers; and a head control device that applies a driving signal to the 15 electromechanical transducing elements to change shapes of the electromechanical transducing elements to change volumes of the corresponding liquid droplet ejection chambers for ejecting liquid droplets through the corresponding nozzles to record an image, the head 20 control device comprising a head driving unit that generates the driving signal including a plurality of cycles of a plurality of driving pulses, and selects and applies one of the driving pulses to one of the electromechanical transducing elements to change the 25 shape of the electromechanical transducing element for

ejecting the liquid droplet, each of the driving pulses having a first portion varying from a first level to a second level for changing the electromechanical transducing element from a first shape to a second shape, 5 and a second portion varying from the second level to the first level for changing the electromechanical transducing element from the second shape back to the first shape to eject the liquid droplet, wherein in at least one driving pulse in each cycle, the second portion 10 includes a third portion varying from the second level to a third level for changing the shape of the electromechanical transducing element to eject the liquid droplet, and a fourth portion subsequent to the second portion varying from the third level to the first level 15 for changing the shape of the electromechanical transducing element back to the first shape.

Preferably, the first portion discharges the electromechanical transducing element from a first potential equivalent to the first level to a second 20 potential equivalent to the second level, the second portion charges the electromechanical transducing element to the first potential to eject the liquid droplet, the third portion charges the electromechanical transducing element to a third potential equivalent to the third level to eject the liquid droplet, and the fourth portion 25

re-charges the electromechanical transducing element to the first potential.

Preferably, the head driving unit selects the fourth portion of said at least driving pulse in each 5 cycle to re-charge the plurality of electromechanical transducing elements at the same time.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other objects, features, and 10 advantages of the present invention will become more apparent from the following detailed description of preferred embodiments given with reference to the accompanying drawings, in which:

FIG. 1 is a perspective view of the machinery 15 of an inkjet recording apparatus as an example of an image recording apparatus according to an embodiment of the present invention;

FIG. 2 is a cross-sectional side view of the machinery of the inkjet recording apparatus of the 20 present embodiment;

FIG. 3 is an exploded perspective view of an example of an inkjet head included in the inkjet recording apparatus of the present embodiment;

FIG. 4 is a cross-sectional view of a portion 25 containing liquid in the recording head of the present

embodiment along the long edge of the portion;

FIG. 5 is an enlarged view of the portion containing liquid in FIG. 4;

FIG. 6 is a cross-sectional view of the 5 portion in FIG. 4 along its short edge;

FIG. 7 is a block diagram schematically showing a control section of the inkjet recording apparatus of the present embodiment;

FIG. 8 is a circuit diagram of the portion 10 subsequent to the decoders in the control section shown in FIG. 7;

FIG. 9 is a cross-sectional view of a principal portion of the inkjet head of the present embodiment for explaining the operation thereof;

15 FIGs. 10A through 10C are cross-sectional views of the same portion of the inkjet head in FIG. 9 in different operation steps;

FIGs. 11A through 11I are timing charts showing the operation of the head control device of the 20 present embodiment;

FIG. 12 shows a head control device of the related art; and

FIGs. 13A through 13H are timing charts showing the operation of the head control device of the 25 related art.

BEST MODE FOR CARRYING OUT THE INVENTION

Below, preferred embodiments of the present invention will be explained with reference to the 5 accompanying drawings.

FIG. 1 shows a perspective view of an inkjet recording apparatus as an example of an image recording apparatus according to an embodiment of the present invention. FIG. 2 is a cross-sectional side view of the 10 inkjet recording apparatus.

The inkjet recording apparatus shown in FIG. 1 and FIG. 2 has a main body 1 and printing machinery 2 accommodated in the main body 1. The printing machinery 2 has a recording head including a carriage 13 movable 15 along a main scan direction, an inkjet head 14 attached to the carriage 13, and an ink cartridge 15. The printing machinery 2 takes in paper 3 fed from a paper feed cassette 4 or a manual feed tray 5, then records a desired image on the paper 3, and then delivers the paper 20 3 to a paper delivery tray 6 attached to the rear side of the apparatus.

In the printing machinery 2, a first guide rod 11 lays across two not-illustrated side boards, serving as a guide member of the carriage 13, and by the first 25 guide rod 11 and a secondary guide rod 12, the carriage

13 is maintained to be able to freely slide in the main scan direction (the axial direction along the guide rod 11). The inkjet head 14 has a number of single color inkjet heads to eject ink droplets of yellow (Y), cyan 5 (C), magenta (M), black (B) or other colors. The inkjet head 14 is attached to the carriage 13 extending downward along the direction of ejecting the ink droplets.

The ink cartridge 15 has a number of ink tanks for storing and supplying ink of the above respective 10 colors to corresponding single color inkjet heads of the inkjet head 14. The ink cartridge 15 is attached to the upper side of the carriage 13, and each ink tank in the ink cartridge 15 is exchangeable when ink therein is running out.

15 The ink cartridge 15 has an air hole on its upper side for communication with the atmosphere, a feeding hole on its lower side for supplying ink to the inkjet head 14, and a porous material of which the inside is filled with ink. Due to the capillary force of the 20 porous material, the ink to be supplied to the inkjet head 14 is maintained at a slightly negative pressure. From the ink cartridge 15, ink is fed to the inkjet head 14.

The first guide rod 11 is inserted into the 25 rear side of the carriage 13 (downstream side along the

paper conveyance direction) while keeping the carriage 13 freely slideable along the first guide rod 11. The front side of the carriage 13 (upstream side along the paper conveyance direction) is firmly held by the secondary 5 guide rod 12 while keeping the carriage 13 freely slideable along the secondary guide rod 12. In order to drive the carriage 13 to scan along the main scan direction, a timing belt 20 is wound between a driving pulley 18 driven by a main scan motor 17 and a driven 10 pulley 19, and is fixed to the carriage 13; due to the forward an backward rotation of the main scan motor 17, the carriage 13 is moved back and forth.

Note that as an example, the inkjet head 14 is described to have a number of single color inkjet heads. 15 The inkjet head 14 may also be configured to have a single head having a number of nozzles ejecting ink droplets of different colors. Further, as described below, the inkjet head 14 is a piezoelectric head, in which at least part of the side wall of a pressure application 20 chamber is formed by a vibrating plate, and this vibrating plate is deformed and vibrated by a piezoelectric element.

On the other hand, in order to convey paper 3 from the paper feed cassette 4 to the position below the 25 inkjet head 14, there are arranged a paper feeding roller

21 and a friction pad 22 for separating and feeding paper
3 from the paper feed cassette 4, a guide member 23 for
guiding the paper 3, a conveyance roller 24 for reversing
the paper 3 for further conveyance, a roller 25 pressed
5 against the surface of the conveyance roller 24, and a
roller 26 for limiting the angle at which paper 3 is sent
out.

The conveyance roller 24 is driven to rotate
by a sub scan motor 27 via a series of gears.

10 A paper guide member 29 is provided
corresponding to the movement range of the carriage 13
along the main scan direction to guide the paper 3 sent
out from the conveyance roller 24 to the position below
the inkjet head 14. On the downstream side along the
15 paper conveyance direction, a roller 31 and a spur 32 are
arranged to send out the paper 3 in the delivery
direction. Further, a delivery roller 33, a spur 34, and
guide members 35 and 36 forming a paper delivery path are
provided to send paper 3 to the paper delivery tray 6.

20 When recording an image on the paper 3, while
the carriage 13 is being moved, the inkjet head 14 is
driven to eject ink droplets to the paper 3 at rest
according to an image signal to record one line; then the
paper 3 is moved by one line so as to record the next
25 line. When a recording completion signal, or a signal

indicating that the present position of the carriage 13 is at the end of the recording region of the paper 3 is received, the above recording operation is ended and the paper 3 is delivered.

5 At a position out of the recording region along the first guide rod 11, a recovery unit 37 is arranged in order to resolve ink ejection problems of the inkjet head 14. The recovery device 37 has a cap, an absorber, and a cleaner. At standby, the carriage 13 is 10 moved to the recovery unit 37, where the recovery unit 37 caps the inject head 14 to keep its nozzle wet to prevent ink ejection problems. In addition, during recording operations, an additional amount of ink is ejected from the inkjet head 14 not for recording but for purging the 15 inkjet head 14, keeping the viscosity coefficients at all the nozzles constant to maintain constant ink ejection performance.

When ink ejection trouble occurs, the nozzle of the inkjet head 14 is sealed by the cap of the 20 recovery unit 37, and through a tube, the absorber takes suction on and evacuates ink, and bubbles in the ink together, from the nozzle, and the cleaner cleans ink and other dust adhering to the nozzle to allow the inkjet head 14 to recover from the ink ejection trouble. The ink 25 drawn out by the absorber is exhausted to a tank for

collecting waste ink, and is stored in an ink absorbing material.

Next, the inkjet head 14 of the inkjet recording apparatus is explained in detail with reference 5 to FIG. 3 through FIG. 6. FIG. 3 is an exploded perspective view showing a configuration of the inkjet head 14; FIG. 4 is a cross-sectional view of a portion of the inkjet head 14 containing ink along its long edge; FIG. 5 is an enlarged view of the core portion of the 10 portion shown in FIG. 4; FIG. 6 is a cross-sectional view of the portion in FIG. 4 along its short edge.

As shown in the above figures, the inkjet head 14 comprises a substrate 41 formed from single crystal silicon, a vibration plate 42 joined with the lower side 15 of the substrate 41, and a nozzle plate 43 formed with many nozzles 45 and joined with the upper side of the substrate 41.

In FIG. 4 through FIG. 6, the reference 46 represents a pressure application chamber formed by the 20 substrate 41, the vibration plate 42, and the nozzle plate 43. The pressure application chambers 46 are in communication with the nozzles 45.

The reference 48 represents a liquid room that feeds ink to the pressure application chamber 46 through 25 an ink feeding channel 47 acting as a liquid resistor.

The side walls of the pressure application chamber 46, the ink feeding channel 47, and the liquid room 48 act as the side surfaces of the substrate 41 and are in contact with ink, and on these side walls, a film 5 50 is formed from an organic resin tolerable to liquid erosion.

As shown in FIG. 3 (also referring to FIG. 4), two lines of stacked piezoelectric elements 52 are provided at positions each corresponding to a pressure 10 application chamber 46. The piezoelectric elements 52 are joined with the lower side of the vibration plate 42 and fixed on a base 53. A spacer 54 is arranged around the two lines of stacked piezoelectric elements 52 and joined with the base 53.

15 As shown in FIG. 5, each piezoelectric element 52 is formed by alternately stacking a piezoelectric film 55 and an inner electrode 56. The expansion and contraction of each piezoelectric element 52 causes expansion and contraction of the pressure application 20 chamber 46. Here, it is assumed that the piezoelectric constant of each piezoelectric element 52 is d_{33} . If a driving signal is applied to one of the piezoelectric elements 52, the piezoelectric element 52 is charged and expands; on the other hand, if the charge stored in the 25 piezoelectric element 52 is released (discharged), the

piezoelectric element 52 contracts. In the base 53 and the spacer 54, a penetration hole is formed to feed ink to the liquid room 48 from the outside. This is the ink feeding hole 49 shown in FIG. 4.

5 The periphery of the substrate 41 and the edges of the vibration plate 42 are joined with a head frame 57 formed from an epoxy resin or PPS (Polyphenylene sulfide) by means of injection molding, and the head frame 57 and the base 53 are fixed by an adhesive agent.

10 Further, in order to apply the driving signal to the piezoelectric element 52, an FPC (Flexible Printed Circuit) cable 58 is connected to the piezoelectric element 52 by solder, or ACF (Anisotropic Conductive Film), or by wire bonding. In the FPC cable 58, a driving circuit (driver IC) 59 is fixed to selectively apply driving signals to piezoelectric element 52.

15 Here, as the substrate 41, a single crystalline silicon substrate with a crystal orientation (110) is processed by the anisotropic etching using an aqueous potassium hydroxide solution (KOH) or other

20 alkaline etching solutions, and resultantly, forming a penetration hole serving as the pressure application chamber 46, grooves serving as the ink feeding channel 47, and a penetration hole serving as the liquid room 48.

25 The vibration plate 42 is made of a metal

plate such as nickel, and is formed by electroforming. As shown in FIG. 6, in order for the vibration plate 42 to deform easily at areas corresponding to the pressure application chambers 46, these areas are formed thin 5 (referred to as recesses 61 below), and the areas of the vibration plate 42 for connection with the piezoelectric elements 52 are formed thick (referred to as projections 62 below). Additionally, the areas of the vibration plate 42 corresponding to the separation walls between two 10 liquid rooms are also formed thick (projections 63 below). The flat upper surface of the vibration plate 42 is connected with the substrate 41 by an adhesive agent, and the ends of the projections 62 are connected with the head frame 57 also with an adhesive agent. Between the 15 base 53 and the projections 63, columns 64 are formed. The columns 64 have the same shape as the piezoelectric elements 52.

The nozzle plate 43 is joined with the substrate 41. In the nozzle plate 43, nozzles 45 are 20 formed to be 10 μm through 30 μm in diameter and at positions corresponding to respective pressure application chambers 46. For example, the nozzle plate 43 may be made from stainless, nickel or other metals, mixtures of a metal and a polyimide resin film or other 25 resins, silicon, or mixtures of the above materials. In

addition, on the surface of the nozzle plate 43 along the ink ejection direction (also referred to as "ejection surface"), a water-shedding film is formed to secure the water-shedding quality of the nozzle plate 43 with 5 respect to ink. This water-shedding film may be formed by any well-known method, for example, plating or coating a water-shedding agent.

Next, the control section of the above inkjet recording apparatus is explained with reference to FIG. 7.

10 FIG. 7 is a block diagram showing the control section of the inkjet recording apparatus of the present embodiment.

The control section of the inkjet recording apparatus of the present embodiment is comprised of an 15 engine controller that includes a printer controller 70 and a head driving circuit 71.

The printer controller 70 includes an interface (I/F) 72 for receiving recording data from a host computer through cables or networks, a CPU 73 for 20 overall control of the printer controller 70, a RAM 74 in which various data are stored, a ROM 75 in which various routines for data processing are stored, an oscillation circuit (OSC) 76, a driving signal generating circuit (GNRTR) 77 that generates the driving signal Vcom to 25 control the operation of the inkjet head 14, and an

interface (I/F) 78 for transmitting the recording data expanded as dot pattern data (bitmap data) and the driving signal to the head driving circuit 71.

The RAM 74 is used as buffers and working memories. The ROM 75 stores various control routines executed by the CPU 73, font data, graphic functions, and various procedures. The CPU 73 reads out the recording data in the reception buffer of the I/F 72, converts them to intermediate codes, and stores the intermediate codes in an intermediate buffer at a specified area of the RAM 74. The CPU 73 first reads out the intermediate codes from the RAM 74, and expands the intermediate codes to dot pattern data using the font data stored in the ROM 75, and then stores the dot pattern data to another specified area of the RAM 74 again.

Once the CPU 73 obtains an amount of the dot pattern data with which the inkjet head 14 can record one line on the paper 3, this amount of the dot pattern data is transmitted to the head driving circuit 71 as the serial data SD through the I/F 78 in synchronization with the clock signal CK generated by the oscillation circuit 76.

The head driving circuit 71 is built into the driver IC 59, and comprises a shift register 81 (SHT-REG) to which the serial data SD containing the clock signal

CK and the recording data from the printer controller 70 are input, a latch circuit 82 (LTCH) that latches the value of the shift register 81 with the latch signal LAT from the printer controller 70, a decoder 83 (DEC) that 5 decodes the data stored at the latch circuit 82 according to the control signal CS from the printer controller 70, a level shift circuit 84 (level shifter: LVL-SHT) that changes the level of the output of the decoder 83, and an analogue switch array (or a switch circuit) 85 that is 10 switched ON or switched OFF by the level shifter 84.

The switch circuit 85 is for inputting the common driving signal Vcom from the driving signal generating circuit (GNRTR) 77 of the printer controller 70, and is connected with each piezoelectric element 52 15 corresponding to a nozzle.

Here, it is assumed that in the inkjet recording apparatus of the present embodiment, the recording data have two-bit data D0 and D1 for each channel of the inkjet head 14 in order to obtain ink droplets of four grade levels in one recording period. 20 The serial recording data SD transmitted to the shift register 81 is first latched by the latch circuit 82, and the latched recording data SD (two-bit data D0 and D1) are decoded at the decoder 83 to which the control signal 25 CS (including signals M0N, M1N, M2N, and M3N) is input.

The levels of the decoded recording data are shifted by the level shifter 84 so as to be able to drive the switches of the switch circuit 85; for example, the levels of the decoded recording data are increased to 5 several tens of volts. The signals of the increased levels are input to the switch circuit 85.

The driving signal V_{com} from the driving signal generating circuit 77 is input to the input terminals of the switch circuit 85, and the piezoelectric 10 elements 52 are connected to the output terminals of the switch circuit 85. Accordingly, for example, in the period when the recording data applied to the switch circuit 85 are "1", a driving pulse obtained from the driving signal V_{com} is applied to the piezoelectric elements 52, and the piezoelectric elements 52 expand and 15 contract in response to the driving pulse. In contrast, in the period when the recording data applied to the switch circuit 85 are "0", no driving pulse is output to the piezoelectric elements 52.

20 FIG. 8 shows an example of a circuit subsequent to the decoder 83 in FIG. 7. Note that FIG. 8 shows only one channel of the whole circuit..

As described above, for each channel of the inkjet head 14, two-bit data D0 and D1 (referred to as 25 "ink ejection data" below) are latched in the latch

circuit 82. Here, as an example, it is assumed that when D1 = 1 and D0 = 1, an ink droplet forming a large dot is ejected, when D1 = 1 and D0 = 0, an ink droplet forming a medium dot is ejected, when D1 = 0 and D0 = 1, an ink droplet forming a small dot is ejected, and when D1 = 0 and D0 = 0, no ink droplet is ejected.

The control signal CS from the printer controller 70 is input to a decoding unit DCN of the decoder 83. The control signal CS includes gate signals M0N, M1N, M2N, and M3N defining time intervals for forming ink droplets of desired grade levels and for recharging the piezoelectric elements 52. The same gate signals M0N, M1N, M2N, and M3N are input to all the decoding units DCN in the decoder 83.

The decoding unit DCN includes four gate circuits G0 through G3, and an OR gate circuit G4. The data D1 and D0 and the gate signals M0N, M1N, M2N, and M3N are input to the four gate circuits G0 through G3 at the same time. The outputs of the four gate circuits G0 through G3 are input to the OR gate circuit G4. The output of the decoding unit DCN is input to an analog switch ASN included in the switch circuit 85 through a level shifter LSN acting as the level shifter 84.

The driving signal Vcom is input to the analog switch ASN, and when the analog switch ASN is switched ON,

a corresponding portion of the driving signal Vcom is applied to the piezoelectric element 52 as a driving signal of the inkjet head 14.

Accordingly, according to the gate signals M0N,
5 M1N, M2N, and M3N, which are respectively related to ejection of large dots, medium dots, small dots and no ejection of dots, the corresponding analog switch ASN of the switch circuit 85 is switched ON or switched OFF.

Specifically, when the output of the decoding 10 unit DCN is "1", the analog switch ASN is ON, and the common driving signal Vcom is applied to the piezoelectric element 52. When the output of the decoding unit DCN is "0", the analog switch ASN is OFF, and the driving signal Vcom is not applied to the piezoelectric 15 element 52, and the output of the decoding unit DCN is in a high impedance state.

Next, with reference to FIG. 9, FIGs. 10A through 10C, and FIGs. 11A through 11I, explanations are made of the operations of the above head control device 20 for controlling ink droplet ejection.

FIG. 9 is a cross-sectional view of a principal portion of the inkjet head 14 of the present embodiment; FIGs. 10A through 10C show the operation of the inkjet head 14 of the present embodiment.

25 First, with reference to FIG. 9 and FIGs. 10A

through 10C, explanations are made of the operations of the pressure application chamber and the piezoelectric element that is operated to pull or push the side wall of the pressure application chamber. Note that although the 5 shapes of the constituent elements of the inkjet head shown in FIG. 9 and FIGs. 10A through 10C are different from those shown in FIG. 3 through FIG. 6, the basic configurations of the inkjet head are the same, therefore, the same reference numerals are used here for the same 10 constituent elements as shown in FIG. 3 through FIG. 6.

The inkjet head 14 shown in FIG. 9 is in a free state, that is, no driving voltage is applied to the piezoelectric element 52. From this state, if turning the power supply ON, the state of the inkjet head 14 changes 15 to that shown in FIG. 10A. The state shown in FIG. 10A is an initial state of the inkjet head 14 during the operation thereof. In the initial state, a bias voltage is applied to the piezoelectric element 52 to charge the piezoelectric element 52. Receiving the charge, the 20 piezoelectric element 52 expands in its thickness direction (the so-called "d33" mode: deformation in the thickness direction), and the volume of the pressure application chamber 46 decreases compared with the equilibrium state as shown in FIG. 9.

25 When an ink droplet is to be ejected from the

nozzle 45, as shown in FIG. 10B, the pressure application chamber 46 is pulled outward first. In detail, the charge stored in the piezoelectric element 52 in the initial state is released (discharged), and the piezoelectric element 52 contracts, therefore, the volume of the pressure application chamber 46 increases. As a result, ink is pulled into the pressure application chamber 46 from an ink tank outside. In the meantime, the meniscus of the nozzle 45 is drawn inward relative to the pressure application chamber 46.

Next, as shown in FIG. 10C, a driving pulse is applied to the piezoelectric element 52 through the cable 58 to rapidly charge the piezoelectric element 52 and expand it again. Accordingly, the volume of the pressure application chamber 46 decreases drastically, ejecting an ink droplet.

In the process, a tiny droplet can be formed by controlling the expansion level of the piezoelectric element 52, for example, at steps smaller than that shown in FIG. 10A. It is possible to delicately control the formation of the tiny droplets and attain more grade levels by making the steps of changing the expansion level of the piezoelectric element 52 sufficiently small,

FIGs. 11A through 11I are timing charts of signals used in the above head control device of the

present embodiment for further explanations of the operations of the head control device.

FIG. 11A shows the waveform of the driving signals V_{com} generated by the driving signal generating circuit 77. In the driving signal V_{com} , there are a driving pulse P_1 for forming a large dot in the period from the time T_0 to the time T_1 , a driving pulse P_2 for forming a medium dot in the period from the time T_1 to time T_2 , and a driving pulse P_3 for forming a small dot in the period from the time T_2 to time T_3 .

In this invention, the driving pulse P_3 contains a component P_{31} after the time T_3 as shown in FIG. 11A, and the component P_{31} rises to a specified level V_b . Furthermore, in this invention, in the time period of the component P_{31} , the inkjet head 14 is not operated to form ink droplets.

FIG. 11B shows a response signal V_{h11} of the piezoelectric element 52 (voltage on the piezoelectric element 52) of a channel for forming a large dot, FIG. 11C shows a response signal V_{h10} of the piezoelectric element 52 of a channel for forming a medium dot, FIG. 11D shows a response signal V_{h01} of the piezoelectric element 52 of a channel for forming a small dot, and FIG. 11E shows a response signal V_{h00} of the piezoelectric element 52 of a channel not ejecting a droplet.

FIG. 11F through 11I show the gate signals M3N, M2N, M1N, M0N input to the decoding unit DCN.

As shown in FIG. 11F through 11I, the signal M3N is "0" in the period from the time T0 to the time T1 and in the period from the time T3 to the time T4, the signal M2N is "0" in the period from the time T1 to the time T2 and in the period from the time T3 to the time T4, the signal M1N is "0" in the period from the time T2 to the time T4, and the signal M0N is "0" in the period from the time T3 to the time T4.

Next, with the above configuration, the operations of ink droplet ejection at different grade levels are explained.

In the period from T0 to T1 of the recording period shown in FIG. 11A, the analog switch ASN corresponding to the piezoelectric element 52 that causes ejection of a large ink droplet to form a large dot is switched ON. That is, the recording data SD in which D1 = 1, D0 = 1, together with the control signal CS in which M3N = 0, are input to the decoding unit DCN so as to eject an ink droplet to form a large dot. Accordingly, the corresponding analog switch ASN is ON in the period from T0 to T1, and the driving pulse P1 residing in the period from T0 to T1 of the driving signal Vcom is applied to the piezoelectric element 52. Because the

driving pulse P_1 is applied to the piezoelectric element 52, as shown in FIG. 11B, the piezoelectric element 52 is re-charged, and the signal V_{h11} (the potential of the piezoelectric element 52) increases from the level of the 5 discharge state to the potential V_b again, ejecting an ink droplet for forming a large dot through the nozzle 45.

During this period, the analogue switches ASN are OFF in other channels that are not required to eject ink droplets for forming large dots, that is, the analog 10 switches ASN are OFF in the channel for ejecting an ink droplet to form a medium dot, the channel for ejecting an ink droplet to form a small dot, and the channel not ejecting ink droplets in this recording period. Therefore, in these channels, the piezoelectric elements 52 start to 15 discharge slightly. Consequently, as shown in FIGs. 11C through 11E, from the time T_0 , the potentials at the piezoelectric elements 52 (that is, the signals V_{h10} , V_{h01} , V_{h00} , respectively) start to decrease slightly from an initial potential V_b .

20 In the period from T_1 to T_2 of the recording period shown in FIG. 11A, the analog switch ASN corresponding to the piezoelectric element 52 that causes ejection of an ink droplet for forming a medium dot is switched ON. In other words, the recording data SD in 25 which $D_1 = 1$, $D_0 = 0$, together with the control signal CS

in which $M2N = 0$, are input to the decoding unit DCN for ejection of an ink droplet to form a medium dot.

Accordingly, the corresponding analogue switch ASN is ON in the period from $T1$ to $T2$, and the driving pulse $P2$ 5 residing in the period from $T1$ to $T2$ of the driving signal V_{com} is applied to the piezoelectric element 52, and an ink droplet for forming a medium dot is ejected from the nozzle 45 in this channel.

In the above step, because the driving pulse 10 $P2$ is applied to the piezoelectric element 52, as shown in FIG. 11C, the piezoelectric element 52 is re-charged, and the signal V_{h10} (the potential of the piezoelectric element 52) is increased from the level of the discharge state to the potential V_b again, ejecting an ink droplet.

15 In addition, because the analog switch ASN is OFF in the channel for ejecting an ink droplet to form a large dot, as shown in FIG. 11B, from the time $T1$, the potential at the piezoelectric element 52 in this channel (the signal V_{h11}) starts to decrease slightly from the 20 potential V_b . Further, because the analog switch ASN remains OFF in the channel for ejecting an ink droplet to form a small dot, as shown in FIG. 11D, the piezoelectric element 52 in this channel continues to discharge, and the potential at the piezoelectric element 52 in this 25 channel (the signal V_{h01}) continues to decrease.

Similarly, because the analog switch ASN remains OFF in the channel not ejecting ink droplets in this recording period, as shown in FIG. 11E, the piezoelectric element 52 in this channel continues to discharge, and the 5 potential at the piezoelectric element 52 in this channel (the signal V_{h00}) continues to decrease. Nevertheless, in the period from T_0 to T_1 , because the analogue switch ASN is ON from T_0 to T_1 in the channel for ejecting an ink droplet to form a large dot (FIG. 11F), the amount of 10 discharge of the piezoelectric element 52 in this channel (the signal V_{h11}) is relatively small compared with that in the channel for forming a small dot and the channel not forming any dots.

In the period from T_2 to T_3 of the recording 15 period shown in FIG. 11A, the analog switch ASN corresponding to the piezoelectric element 52 causing ejection of an ink droplet for forming a small dot is switched ON. In other words, the recording data SD in which $D_1 = 0$, $D_0 = 1$, together with the control signal CS 20 in which $M_{1N} = 0$, are input to the decoding unit DCN for ejection of an ink droplet for forming a small dot. Accordingly, the corresponding analog switch ASN is ON in the period from T_2 to T_3 , and the driving pulse P_3 residing in the period from T_2 to T_3 of the driving 25 signal V_{com} is applied to the piezoelectric element 52 in

this channel, and an ink droplet for forming a small dot is ejected from the nozzle 45 in this channel.

In the above step, because the driving pulse P3 is applied to the piezoelectric element 52 that causes 5 ejection of an ink droplet for forming a small dot, as shown in FIG. 11D, the piezoelectric element 52 is recharged and the signal Vh01 is increased from the level of the discharge state to the potential Vb again, ejecting an ink droplet and forming a small dot.

10 In addition, because the analog switch ASN is OFF in the channel for ejecting an ink droplet to form a middle dot, as shown in FIG. 11C, from the time T2, the potential at the piezoelectric element 52 in this channel (the signal Vh10) starts to decrease slightly from the 15 potential Vb. Further, because the analog switch ASN remains OFF in the channel for ejecting an ink droplet to form a large dot, as shown in FIG. 11B, the piezoelectric element 52 in this channel continues to discharge, and the potential at the piezoelectric element 52 in this 20 channel (the signal Vh11) continues to decrease.

Similarly, because the analog switch ASN remains OFF in the channel not ejecting ink droplets in this recording period, as shown in FIG. 11E, the piezoelectric element 52 in this channel continues to discharge, and the 25 potential at the piezoelectric element 52 in this channel

(the signal V_{h00}) continues to decrease.

In the period from T_2 to T_3 , the analog switches ASNs are OFF in the channel forming a large dot, the channel forming a medium dot and the channel not forming any dots. For the same reason as described above, in the period from T_2 to T_3 , because the duration of discharging of the piezoelectric elements 52 is longest in the channel not forming any dots (FIG. 11E), and shortest in the channel ejecting an ink droplet for forming a medium dot (FIG. 11C), the amount of discharge of the piezoelectric element 52 is smallest in the channel forming a medium dot, the second smallest in the channel forming a large dot, and the largest in the channel not forming any dots.

Note that the driving pulse P_3 causing ejection of an ink droplet for forming a small dot increases until the time T_3 ; it does not rise to the potential V_b . That is, the driving pulse P_3 causes ejection of an ink droplet for forming a small dot, but in this ejection, the piezoelectric element 52 is not sufficiently expanded. The piezoelectric element 52 remains in this state after the time T_3 .

Then, in the period from T_3 to T_4 of the recording period shown in FIG. 11A, the gate signals M_{3N} , M_{2N} , M_{1N} , and M_{0N} are all "0" ($M_{3N} = M_{2N} = M_{1N} = M_{0N} = 0$),

so the analog switches ASN are ON in all channels despite the values of the recording data D1 and D0, and therefore, the piezoelectric elements 52 in all channels are recharged, and the piezoelectric element 52 in the channel 5 for forming a small dot is charged following the driving pulse P3.

The above re-charging in the period from the time T3 to the time T4 is performed by using the signal P31, which is a component of the driving pulse P3 10 subsequent to the time T3, at which an ink droplet for forming a small dot is ejected.

In addition, as shown in FIG. 11B through FIG. 11E, the level of the signal component P31 at the time T3 is slightly lower than the potential Vb, and the signal 15 component P31 rises from this level to the potential Vb.

At the time T3, the amounts of discharge of the piezoelectric elements 52 in different channels for forming dots of different sizes are slightly different, hence, the potentials of the piezoelectric elements 52 in 20 different channels are slightly different at time T3. From these potentials, the piezoelectric elements 52 in different channels are re-charged to the potential Vb in the period from T3 to T4.

Due to the re-charging, the piezoelectric 25 elements 52 in different channels expand and tend to

eject ink from the corresponding pressure application chambers. However, in the period from T3 to T4, the changes of the potentials of the piezoelectric elements 52 in different channels are small, and do not cause ink 5 ejection.

Summarizing the above description, the piezoelectric element is re-charged by the signal P31 that rises from a slightly lower level to the target potential Vb, but not by a flat level at the target 10 potential Vb, thus re-charging of the piezoelectric element can be started earlier than when using a flat level Vb. Consequently, the duration of re-charging by the flat level Vb becomes short.

Since the change of the potential of the 15 piezoelectric element during the re-charging is small, the re-charging does not influence the next ink ejection operation.

In addition, according to the present invention, a plurality of piezoelectric elements can be 20 re-charged at the same time, so the associated circuits can be made simple.

Further, since the signal P31 is applied to the piezoelectric element at time T3 after the ink droplet ejection operation induced by the driving pulse 25 P3, the re-charging by the signal P31 does not influence

the ink droplet ejection operation, and reduces mistaken ink ejection due to re-charging.

Furthermore, since the signal P31 is included in one recording period (from the time T0 to the time T4), 5 it is not necessary to allocate an additional time period for the re-charging signal, so it is possible to increase the speed of image formation and improve image quality.

If the time period elapsed after the analog switch is switched OFF and the amount of discharge of the 10 piezoelectric elements after the time period elapsed are known (assuming the piezoelectric elements have been charged to the target potential V_b , that is, the initial potentials of the piezoelectric elements are V_b), and if it can be assured that mistaken ejections will not occur 15 in other channels from these information elements, it is sufficient to set only the gate signals M0N and M1N to "0" in the period from T3 to T4 so as to re-charge only the piezoelectric elements in the channels not ejecting ink droplets.

20 By doing this, the discharging states of the piezoelectric elements in all channels last for no more than two periods, and this allows a more stable recording operation. In addition, the current generated during re-charging may be distributed in a number of periods, and 25 this further reduces the complication of the control

signals.

While the present invention has been described with reference to specific embodiments chosen for purpose of illustration, it should be apparent that the invention 5 is not limited to these embodiments, but numerous modifications could be made thereto by those skilled in the art without departing from the basic concept and scope of the invention.

For example, in the above embodiment, an 10 inkjet recording apparatus including an inkjet head ejecting ink droplets is used as an example to describe the image recording apparatus of the present invention. The present invention is not limited to this; it is applicable to any image recording apparatus including 15 liquid droplet ejection devices ejecting droplets of any other kind of liquid, for example, a liquid droplet ejection head for ejecting droplets of liquid resist for use of patterning in a semiconductor fabrication process, and a liquid droplet ejection head for ejecting droplets 20 of DNA samples.

Summarizing the effect of the invention, according to the head control device of the present invention, it is possible to re-charge an electromechanical transducing element using a driving 25 pulse without providing an additional re-charging time in

a recording period, and this makes it possible to make the time of re-charging the electromechanical transducing element short, and improve image quality and image formation speed.

5 This patent application is based on Japanese priority patent application No. 2002-182284 filed on June 24, 2002, the entire contents of which are hereby incorporated by reference.

CLAIMS

1. A head control device that applies a driving signal to an electromechanical transducing element to change a shape of the electromechanical transducing element to change a volume of a liquid droplet ejection chamber filled with a liquid for ejecting a liquid droplet through a nozzle in communication with the liquid droplet ejection chamber,
10 the head control device comprising:

a head driving unit that generates the driving signal including a plurality of cycles of a plurality of driving pulses, and selects and applies one of the driving pulses to the electromechanical transducing element, each of the driving pulses having a first portion varying from a first level to a second level for changing the electromechanical transducing element from a first shape to a second shape, and a second portion varying from the second level to the first level for
15 changing the electromechanical transducing element from a second shape back to the first shape to eject the liquid droplet,
20

wherein

25 in at least one driving pulse in each cycle, the second portion includes:

a third portion varying from the second level to a third level for changing the shape of the electromechanical transducing element to eject the liquid droplet; and

5 a fourth portion subsequent to the second portion varying from the third level to the first level for changing the shape of the electromechanical transducing element back to the first shape.

10 2. The head control device as claimed in claim 1, wherein

the first portion discharges the electromechanical transducing element from a first potential equivalent to the first level to a second 15 potential equivalent to the second level;

the second portion charges the electromechanical transducing element to the first potential to eject the liquid droplet;

20 the third portion charges the electromechanical transducing element to a third potential equivalent to the third level to eject the liquid droplet; and

the fourth portion re-charges the electromechanical transducing element to the first 25 potential.

3. An image recording apparatus, comprising:
a liquid droplet ejection head including a
plurality of liquid droplet ejection chambers each filled
5 with a liquid and communicating with a nozzle and a
plurality of electromechanical transducing elements in
correspondence with the liquid droplet ejection chambers;
and
a head control device that applies a driving
10 signal to the electromechanical transducing elements to
change shapes of the electromechanical transducing
elements to change volumes of the corresponding liquid
droplet ejection chambers for ejecting liquid droplets
through the corresponding nozzles to record an image,
15 the head control device comprising:
a head driving unit that generates the driving
signal including a plurality of cycles of a plurality of
driving pulses, and selects and applies one of the
driving pulses to one of the electromechanical
20 transducing elements to change the shape of the
electromechanical transducing element for ejecting the
liquid droplet, each of the driving pulses having a first
portion varying from a first level to a second level for
changing the electromechanical transducing element from a
25 first shape to a second shape, and a second portion

varying from the second level to the first level for changing the electromechanical transducing element from the second shape back to the first shape to eject the liquid droplet,

5 wherein

 in at least one driving pulse in each cycle, the second portion includes:

 a third portion varying from the second level to a third level for changing the shape of the 10 electromechanical transducing element to eject the liquid droplet; and

 a fourth portion subsequent to the second portion varying from the third level to the first level for changing the shape of the electromechanical 15 transducing element back to the first shape.

4. The image recording apparatus as claimed in claim 3, wherein

 the first portion discharges the 20 electromechanical transducing element from a first potential equivalent to the first level to a second potential equivalent to the second level;

 the second portion charges the electromechanical transducing element to the first 25 potential to eject the liquid droplet;

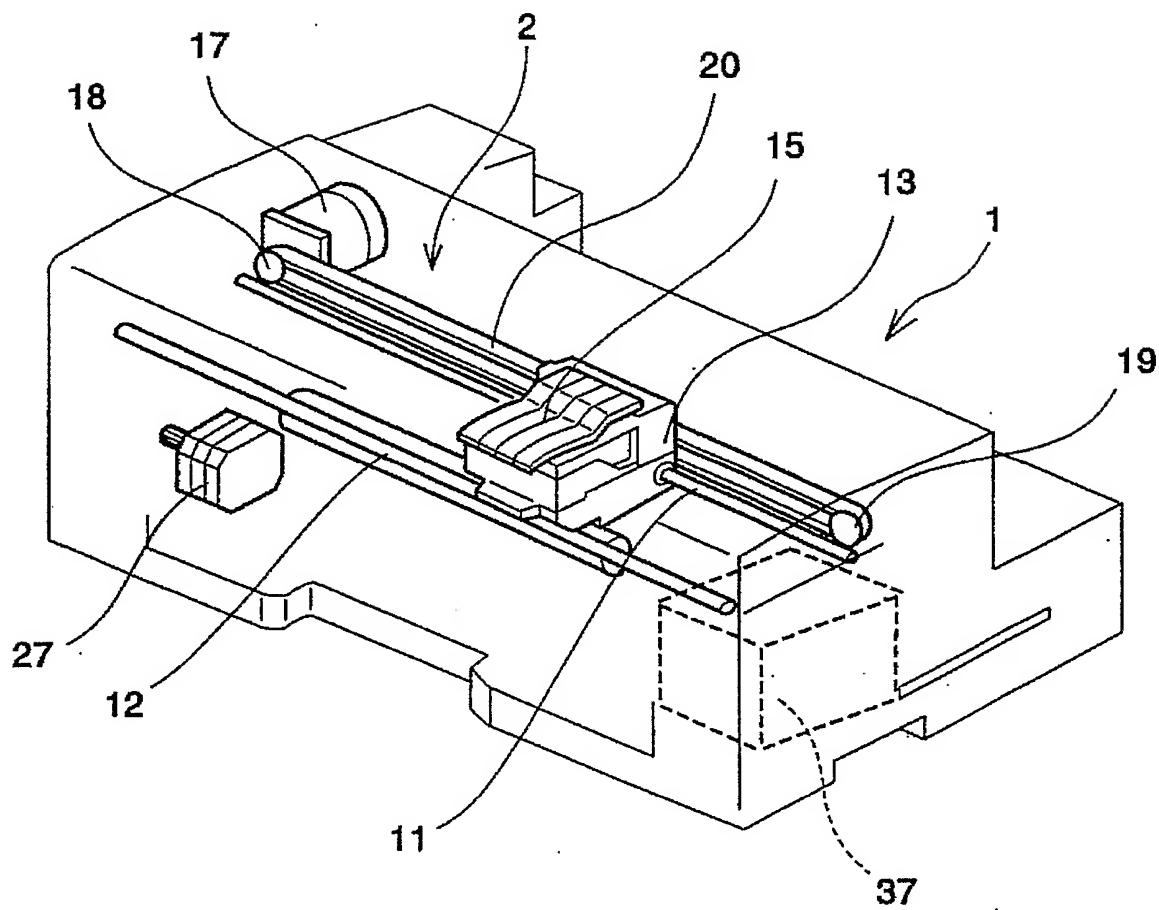
the third portion charges the electromechanical transducing element to a third potential equivalent to the third level to eject the liquid droplet; and

5 the fourth portion re-charges the electromechanical transducing element to the first potential.

5. The image recording apparatus as claimed in
10 claim 4, wherein the head driving unit selects the fourth portion of said at least one driving pulse in each cycle to re-charge the plurality of electromechanical transducing elements at the same time.

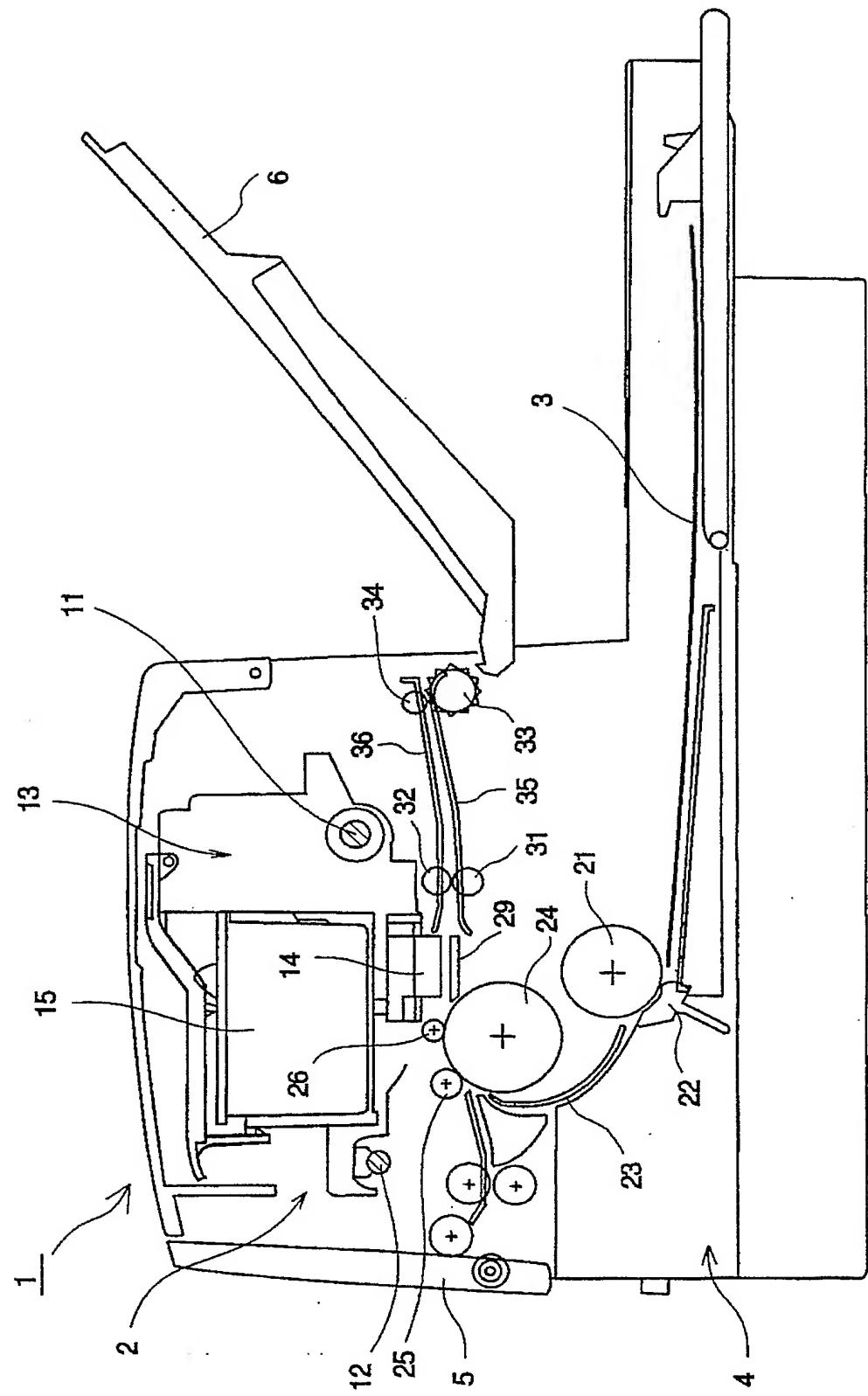
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FIG.1



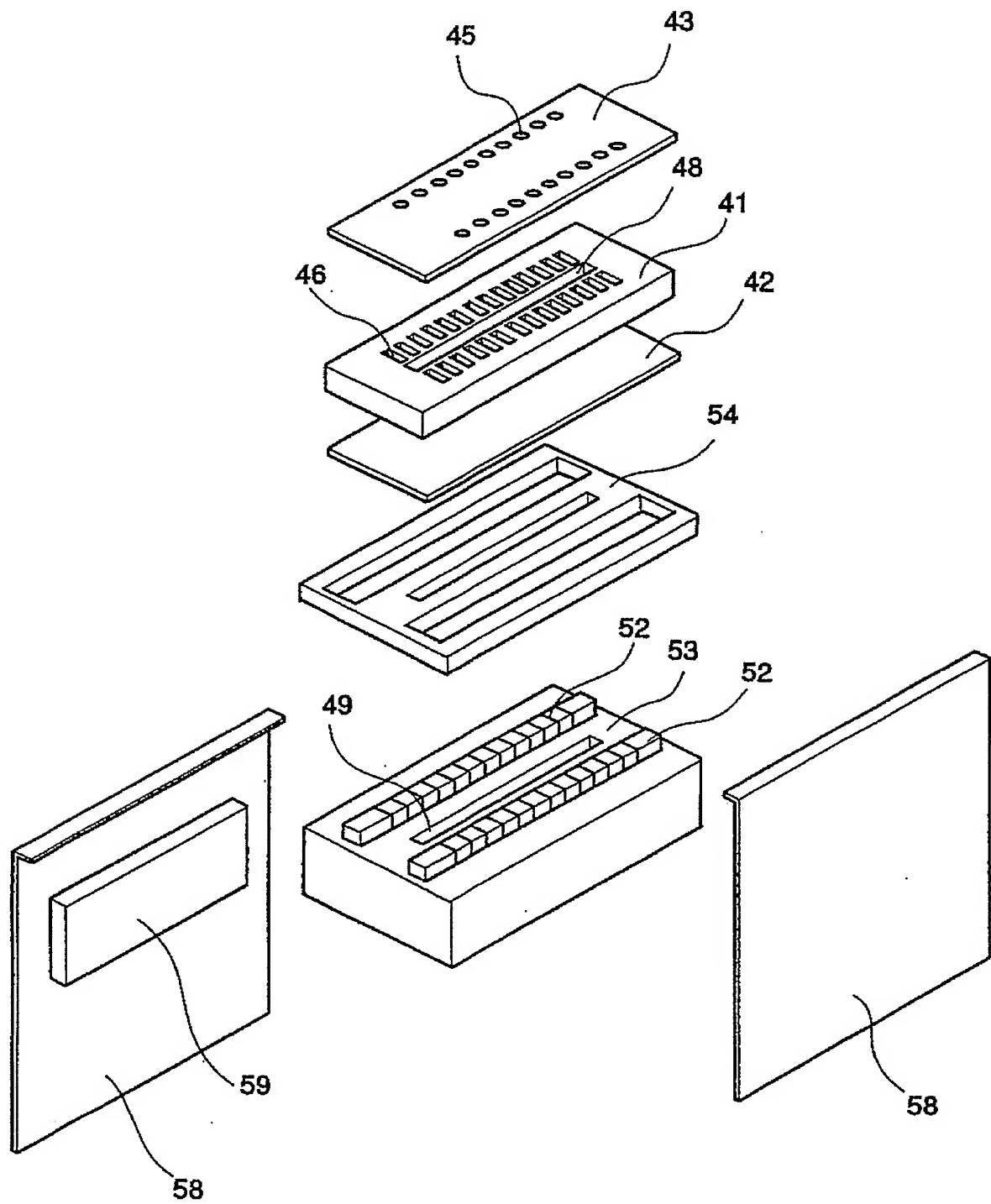
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FIG.2



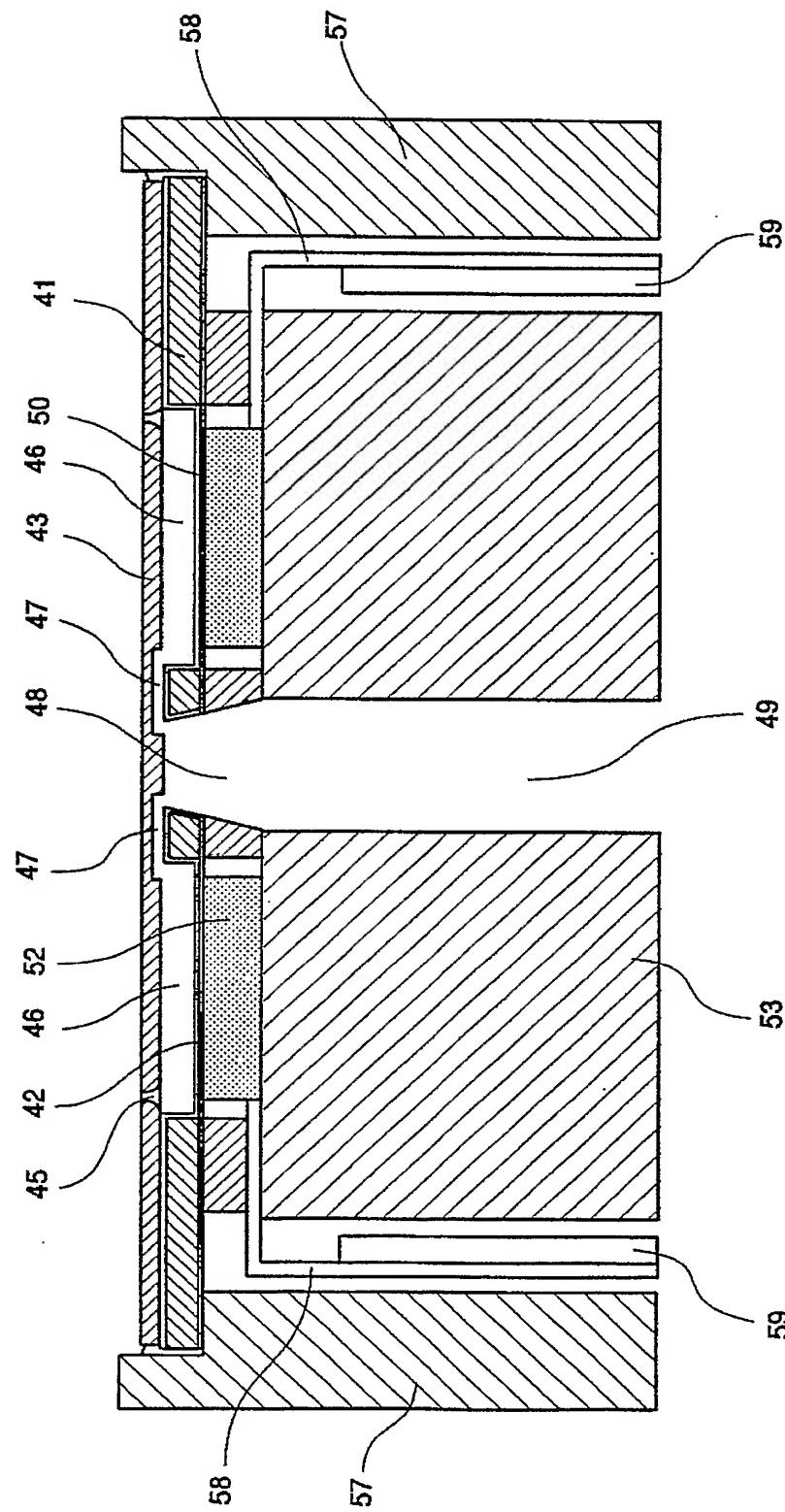
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FIG.3



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FIG.4



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FIG.5

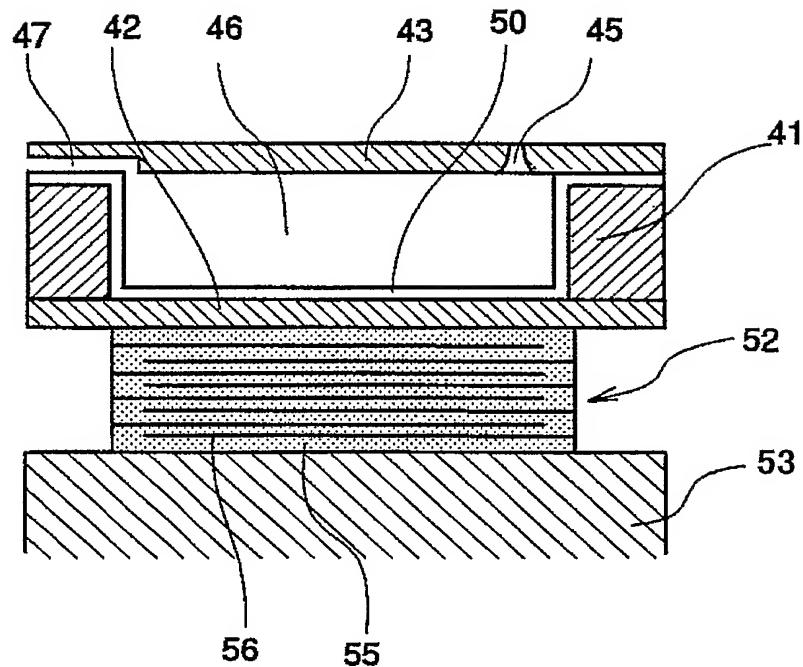
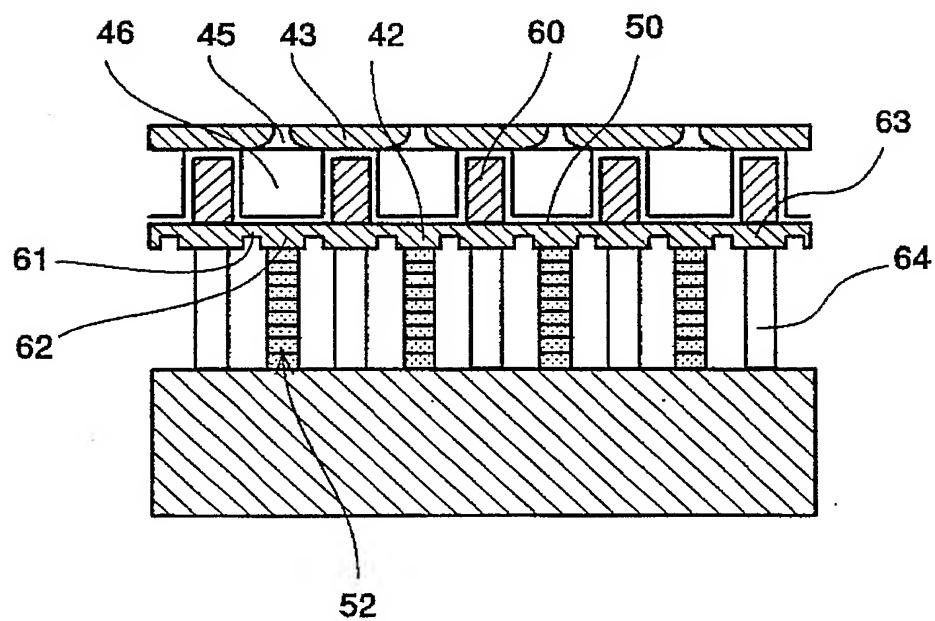
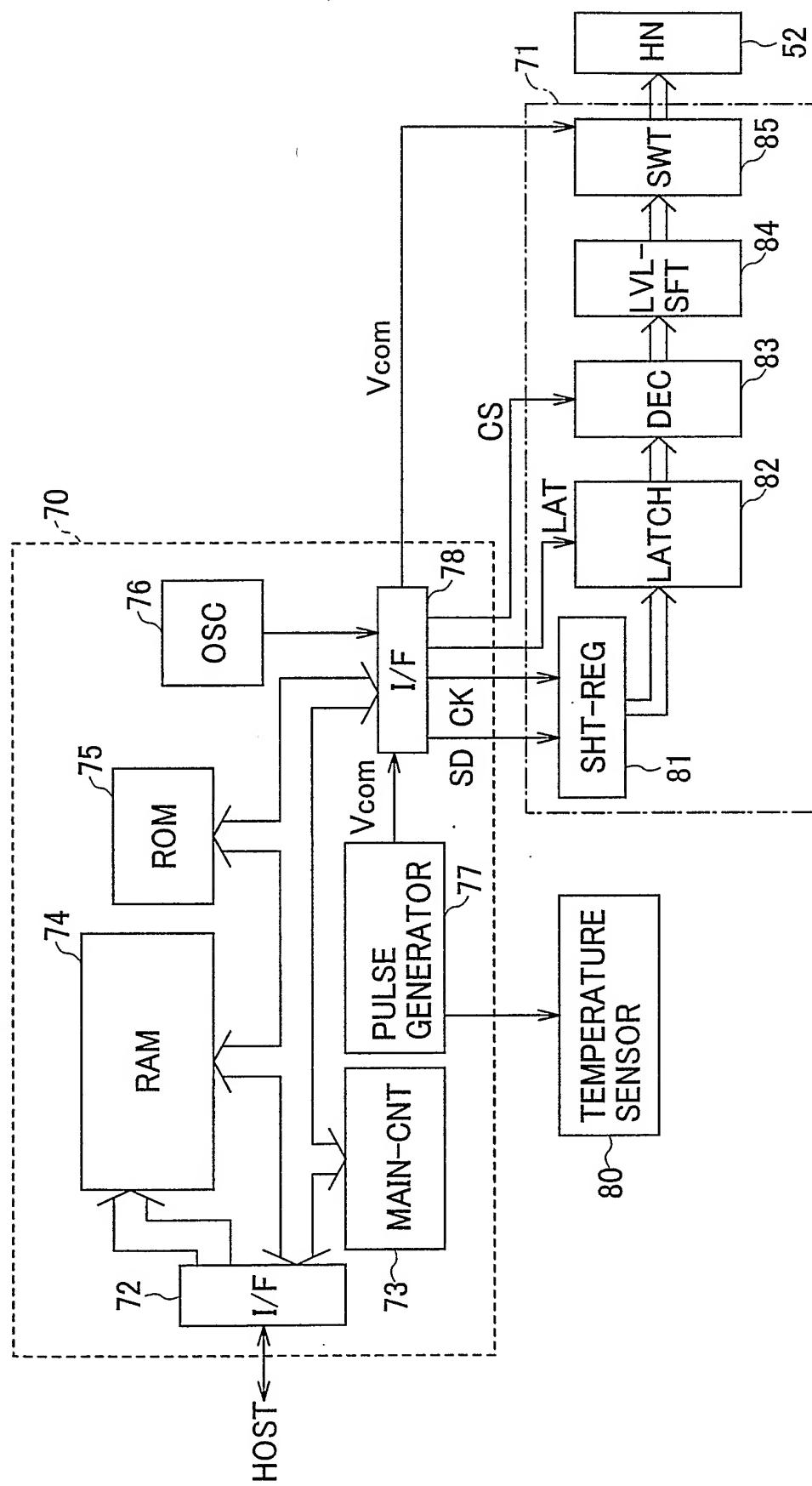


FIG.6



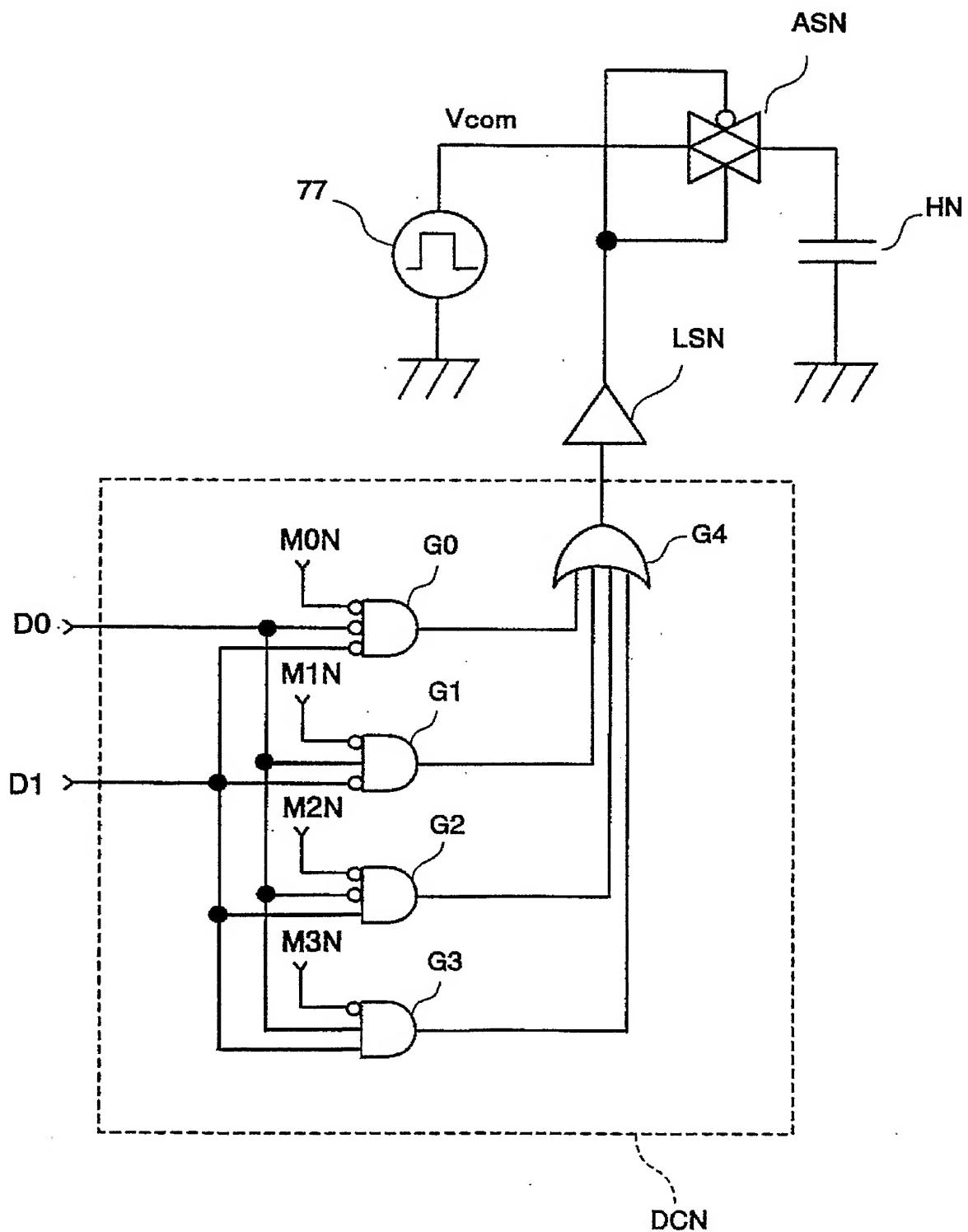
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FIG. 7



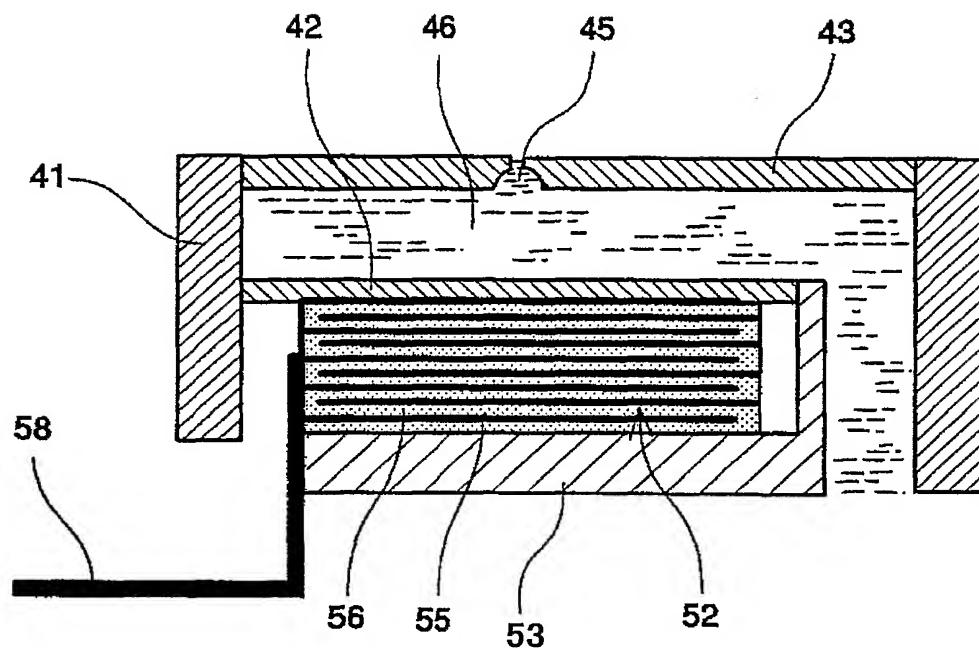
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FIG.8



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FIG.9



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FIG.10A

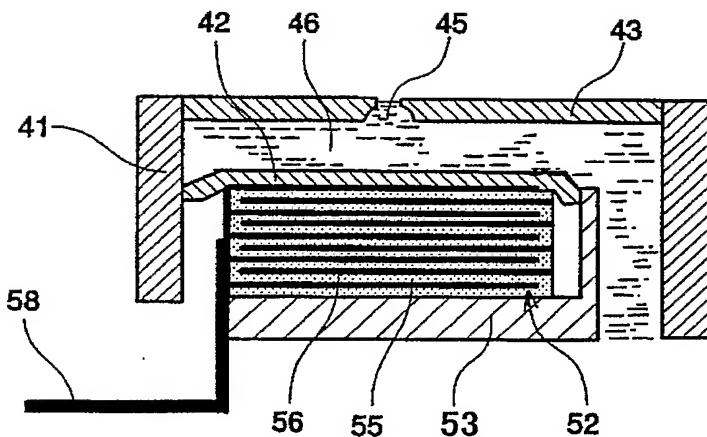


FIG.10B

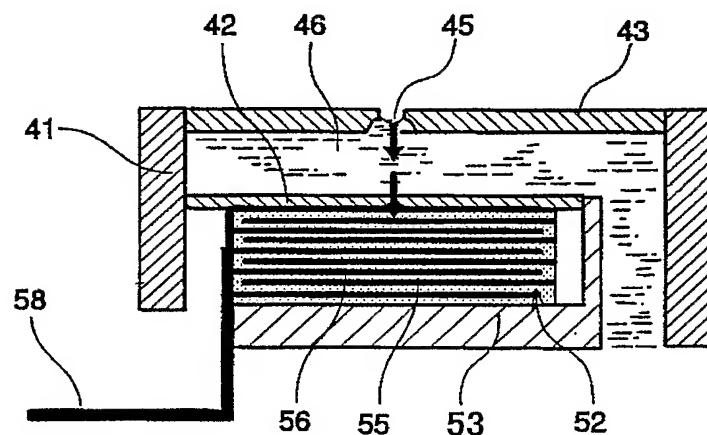
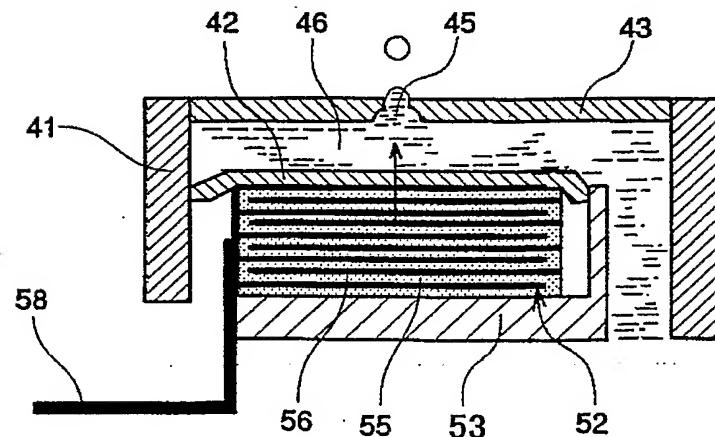
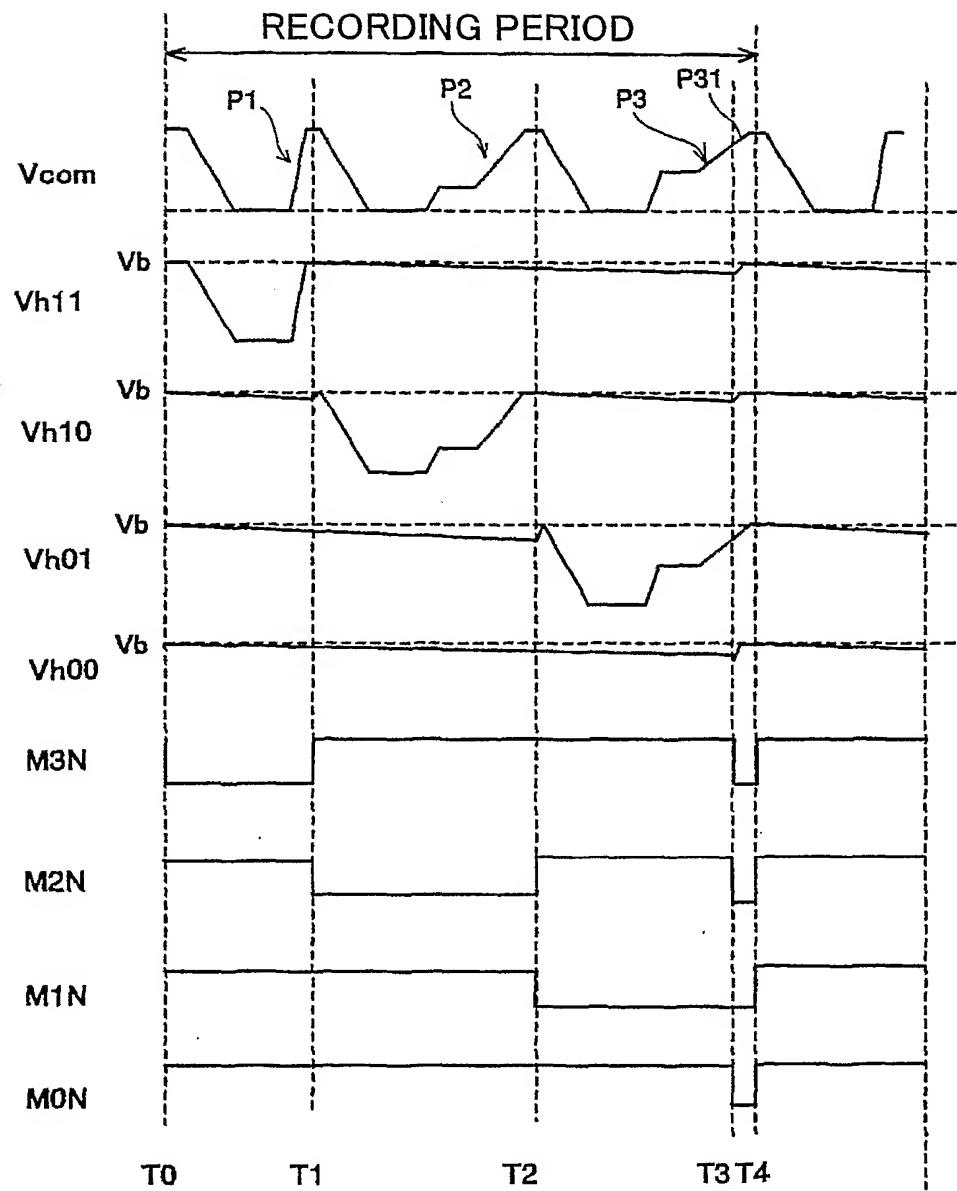


FIG.10C

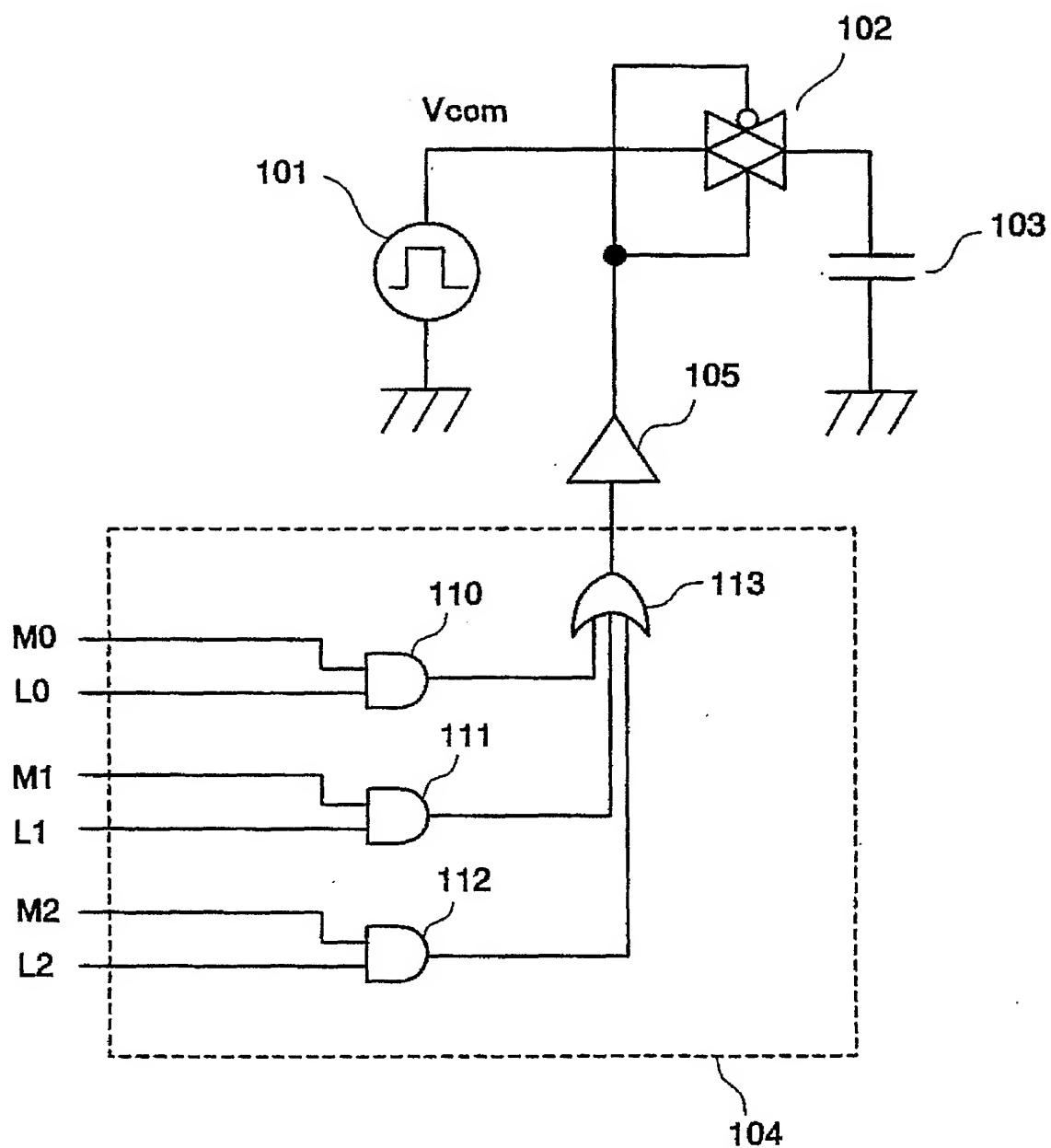


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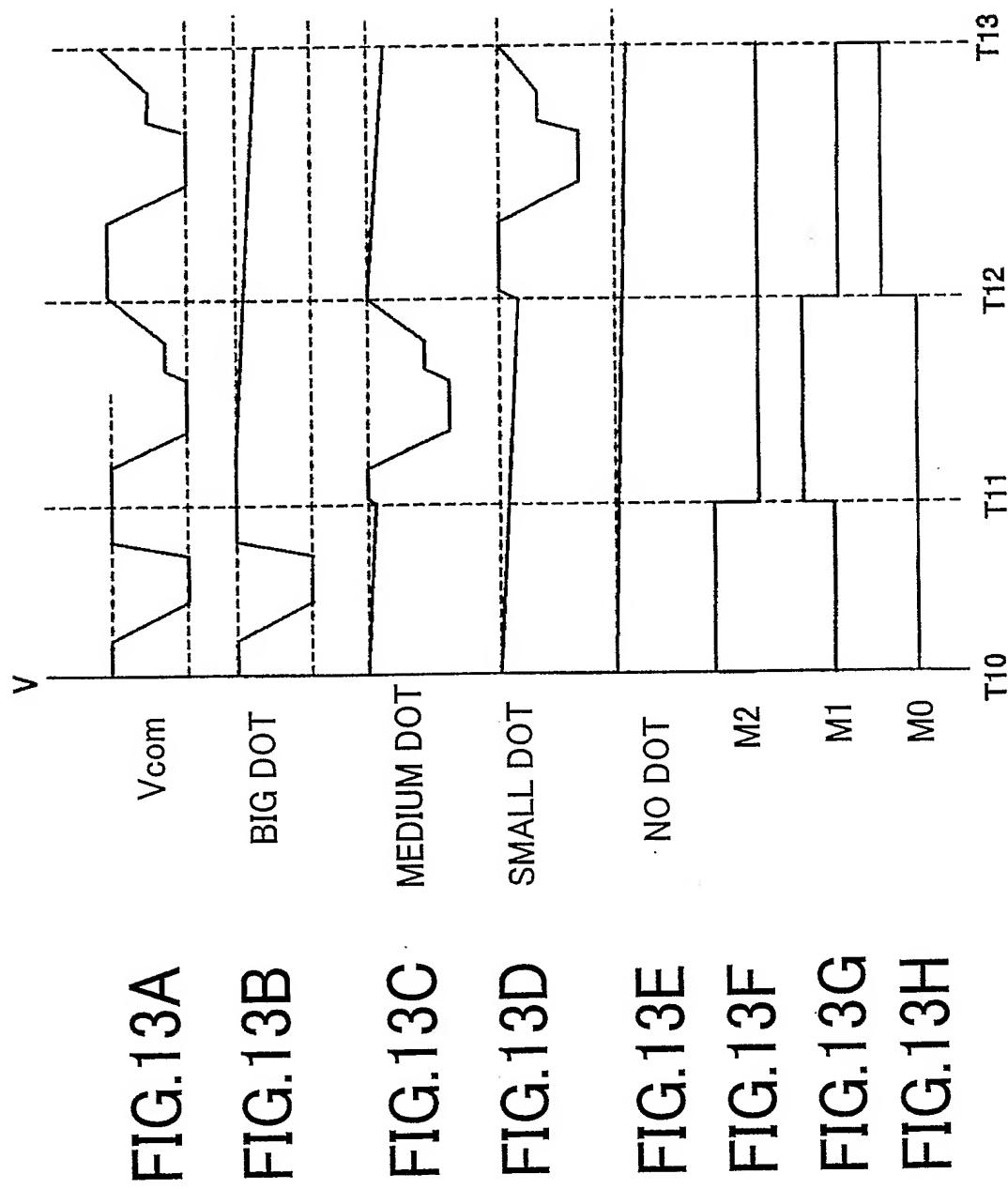
FIG.11A**FIG.11B****FIG.11C****FIG.11D****FIG.11E****FIG.11F****FIG.11G****FIG.11H****FIG.11I**

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FIG.12



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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP03/07882

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl⁷ B41J2/045

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int.Cl⁷ B41J2/045

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
 Japanese Utility Model Gazette 1926-1996, Japanese Publication of Unexamined Utility Model Applications 1971-2003, Japanese Registered Utility Model Gazette 1994-2003, Japanese Gazette Containing the Utility Model 1996-2003

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 6371587 B1 (Seiko Epson Corporation) 2002.04.16 SEE WHOLE DOCUMENT, FIG. 8 & JP 2002-1948 A	1-5
Y	JP 2001-10035 A (Seiko Epson Corporation) 2001.01.16 SEE WHOLE DOCUMENT, FIG. 1-16 (Family: none)	1-5
A	JP 04-310748 A (Seiko Epson Corporation) 1992.11.02 SEE WHOLE DOCUMENT, FIG. 1-4 (Family: none)	1-5
A	JP 2000-43245 A (Fujitsu Limited) 2000.02.15 SEE WHOLE DOCUMENT, FIG. 1-10 (Family: none)	1-5
A	JP 09-234865 A (Citizen Watch Co., LTD) 1997.09.09 SEE WHOLE DOCUMENT, FIG. 1-10 (Family: none)	1-5

 Further documents are listed in the continuation of Box C. See patent family annex.

* Special categories of cited documents:	
"A"	document defining the general state of the art which is not considered to be of particular relevance
"E"	earlier application or patent but published on or after the international filing date
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O"	document referring to an oral disclosure, use, exhibition or other means
"P"	document published prior to the international filing date but later than the priority date claimed
"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2001-113695 A (Seiko Epson Corporation) 2001.04.24 SEE WHOLE DOCUMENT, FIG.1-21 (Family:none)	1-5